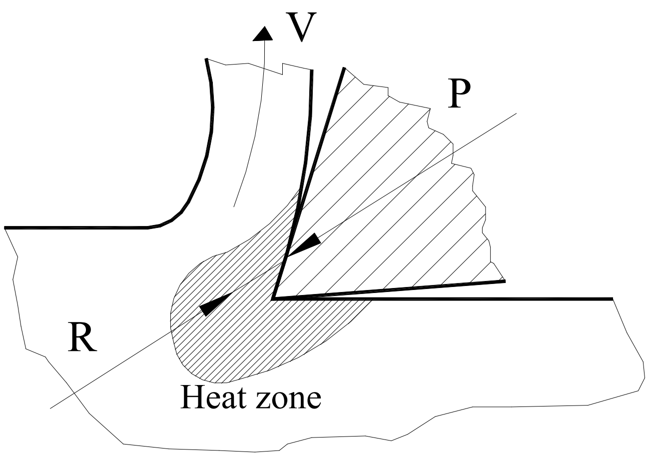
# 3 Cutting Tool materials

## 3.1 Cutting Environment:

During the cutting process, the cutting tool is subjected to:

- High pressure, P
- High temperatures
- Sliding friction along the tool-chip interface and along the machined surface

Consequently, a cutting tool must possess several important properties.




## 3.2 Properties required for tool materials

1- Hardness: Tool hardness >> w.p. hardness → to penetrate.

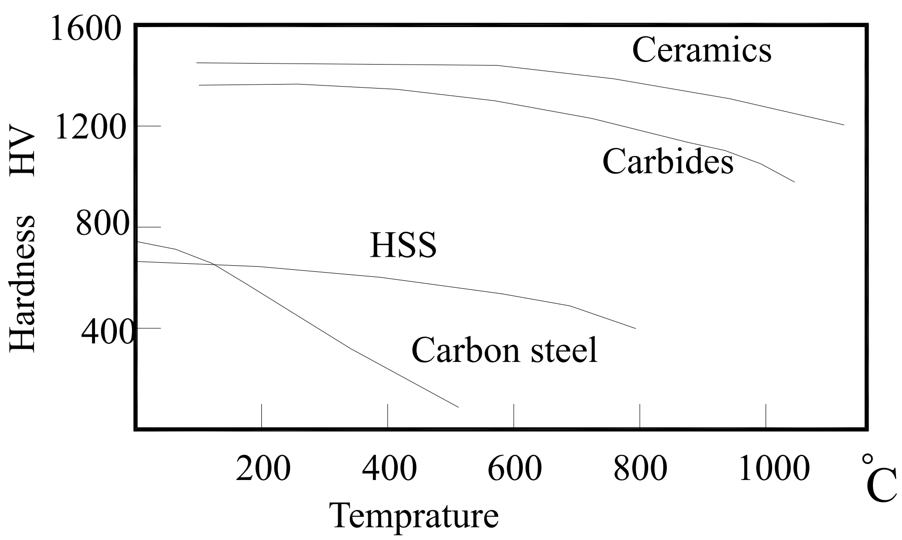
2- Hot hardness: it is the ability of tool material to retain hardness at high temperature (ceramic is the best as shown in the figure below).

3- Wear resistance: it is the ability of tool material to resist wear.

4- Strength and toughness: σ → to withstand mechanical stress. Toughness → to withstand impacts and shocks.

5- High thermal conductivity ($K$): $K$ → heat is absorbed and conducted quickly → ↓ temperature of cutting zone.

6- Low cost and easy fabrication.

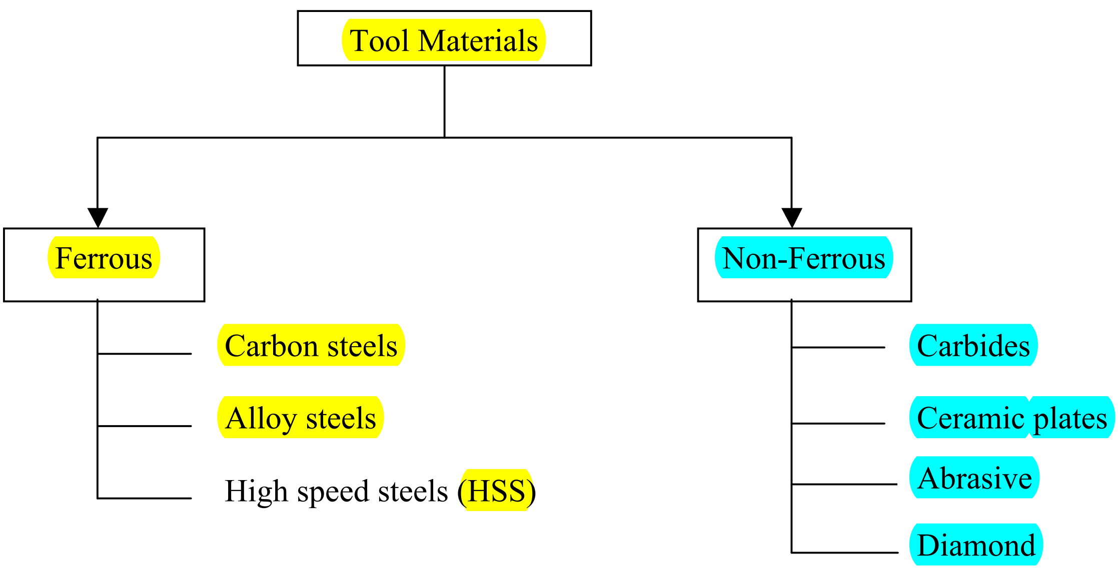


### 3.3 Main types of tool failure:

The severe cutting conditions cause the tool failure after certain cutting interval. The tool failure happens when the tool fails to cut properly. There are different types of tool failure such as:

1. **Thermal failure:** At very high cutting speeds → the cutting temperature ↑↑ and cause the following:
   - Hardness of the main cutting edge ↓ → tool material is softened → σ ↓ → sudden tool failure.
   - The tool material may melts due to excessive ↑ temperature.
   - Thermal shock → cracks on tool face and flank.
2. **Mechanical failure**: It happens when:
   - The applied load > strength of the tool.
   - The cutting forces increase due to wear.
   - The tool strength σ is weakened due to ↑ temperature.
3. **Gradual wear**: It is the most common type. It is caused by the sliding of the chips on tool face and the sliding of tool over the machined surface. The main types of tool wear are abrasion, adhesion and diffusion

### 3.4 Classification of tool materials




#### 3.4.1 Carbon tool steels and Alloy steels

- Carbon steels are the oldest of tool materials and have been used widely for drills, hand tools and wood working tools.
- Low-alloy and medium-alloy steels were developed later for similar applications but with longer tool life.

- These steels do not have sufficient hot hardness and wear resistance for cutting at high speeds, as shown in the previous figure.

### 3.4.2 High speed steels (HSS)

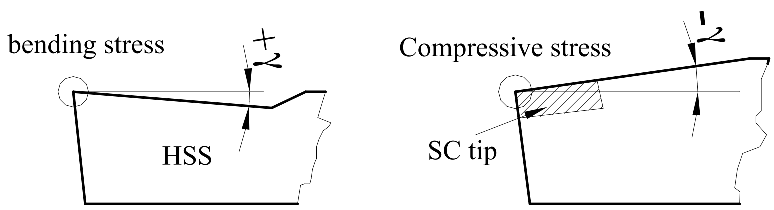
- HSS is used for a wide variety of tools. The main alloying elements are tungsten (W), molybdenum (Mo), chromium (Cr), vanadium (V) and cobalt (Co).
- There are two basic types of HSS:

1- The M series (Mo up to 10%)is used when shock resistance is required.

2- The T series (W up to 18%) is used when high heat resistance is required.

### 3.4.3 Carbides

- It is known also as sintered or cemented carbides
- The two basic groups of carbides used for machining are tungsten carbide (WC) and titanium carbide (TiC).
- WC is a composite material consisting of WC particles (1-5 μm in size) bonded together in a cobalt matrix, which is pressed and sintered into the desired shapes using powder metallurgy
- As the cobalt (Co) content increases the strength, hardness and wear resistance of WC decrease while its toughness increases because of the higher toughness of cobalt.
- TiC has higher wear resistance than WC. With a nickel-molybdenum alloy as the matrix, TiC is suitable for machining hard materials, mainly steels and cast iron and for cutting at speeds higher than those for WC.
- Design of HSS and Sintered carbides tools




### 3.4.4 Ceramics

- Ceramic tool materials consist of fine-grains of high purity aluminum oxide ($Al_2O_3$) or Silicon nitride (SiN). They are cold pressed into insert shapes then sintered at high temperature and pressure.
- The properties of ceramics such as hardness, hot hardness, thermal resistance and wear resistance are significantly higher than carbide tools.
- Additions of titanium carbides and zirconium oxide improve properties such as toughness and thermal-shock resistance.
- Thus Ceramics improve productivity, accuracy and $R_a$ but they are expensive and brittle.

### 3.4.5 Abrasives

- Main types of abrasives are $Al_2O_3$, SiC, $B_4C$, … etc.
- Used for grinding, honing, lapping and super finishing.
- Bonded or pressed to form a tool shape (like the grinding wheel)
- Hardness allows them to machine very hard materials to close tolerances.

### 3.4.6 Diamond

- It is the hardest tool material
- It consists of very small synthetic crystals bonded by a high-pressure, high temperature process to a thickness of about 0.5-1 mm and bonded to a carbide substrate.
- Diamond tools can be used at almost any speed and suitable for light uninterrupted finishing cuts. It is also used as an abrasive in grinding and polishing operations and as coatings.

## 3.5 Coated Tools

New alloys and materials are being developed continuously. These materials have high strength and toughness and chemically reactive with tool materials. The difficulty of machining these materials has led to important development of coated tools (Carbides, ceramics and diamond) such as:

1. **Laminated coated tools:** The tool face is coated with a thin layer of 2-10 μm of a coating material of high war resistance such as $Al_2O_3$, TiN, TiC and TiCN.
2. **Chemical vapor deposition:** of a thin layer (2-4 μm) of a coating material.

**A comparison between cutting tool materials:**

| | **Carbon steel and alloy steel** | **High speed steel** | **Carbides** | **Ceramics** | **Diamond** |
|---|---|---|---|---|---|
| **Cutting temperature ° C** | Up to 250 | Up to 600 | Up to 1000 | Up to 1200 | |
| **Cutting speed m/min** | Up to 20 | Up to 60 | Up to 250 | Up to 750 | Any speed |
| **Depth of cut** | Light to medium | Light to heavy | Light to heavy | Light to heavy | Very light |
| **Finish obtainable** | Rough | Rough | Good | Very good | Excellent |
| **Hot hardness** | ——— Increasing ———→ | | | | |
| **Toughness** | ←——— Increasing ——— | | | | |
| **Impact strength** | ←——— Increasing ——— | | | | |
| **Wear resistance** | ——— Increasing ———→ | | | | |
| **Thermal shock resistance** | ←——— Increasing ——— | | | | |